

# Moment Analysis Applied to LMC Star Clusters

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## ABSTRACT

Statistical moment-based ellipse fitting was performed on observations of Large Magellanic Cloud clusters, confirming that trends are evident in their position angles and ellipticities, as had been reported in the literature. Artificial cluster images with known parameters were generated, and subjected to the same analysis techniques, revealing apparent trends caused by stochastic processes. Caution should therefore be exercised in the interpretation of observational trends in young LMC clusters.

**Key words:** Star Clusters – Ellipticity – Large Magellanic Cloud

## 1 INTRODUCTION

Globular clusters belonging to the Galaxy are essentially spherical in shape, with a mean ellipticity (defined as for elliptical galaxies) of 0.12 (Shapley, 1930). One of the most elliptical galactic globular clusters is  $\omega$  Centauri with ellipticity estimates of 0.14 (Dickens and Woolley, 1967) and 0.19 (Van den Bergh, 1983; Frenk & Fall, 1983).

It has been known for many years that some of the brightest old clusters in the Magellanic Clouds are strongly flattened (Van den Bergh, 1983). Geisler & Hodge (1980) used microdensitometry of photographic plates for 25 Large Magellanic Cloud (LMC) star clusters, and found a mean ellipticity of 0.22, which they commented was far above the galactic mean. They also noted some internal variations in the position angle of the fitted ellipses as well as in the ellipticity itself. Radial variations were reported by Geyer, Hopp & Nelles (1983) and Zepka & Dottori (1987), and commented on by Kontizas et al. (1989) as a possible explanation for the discrepancies in the elliptical parameters derived by different investigators for the same clusters (see Table 1). Van den Bergh (1983) noted that the more luminous LMC clusters of any age are more flattened than fainter clusters. Frenk & Fall (1982) estimated by eye 52 LMC cluster ellipticities, although their mean value was  $0.12 \pm 0.07$ , which should be compared with their mean estimate for 93 galactic globulars of  $0.08 \pm 0.05$ . Using the age classes of Searle, Wilkinson & Bagnuolo (1980), Frenk & Fall noted an apparent 97 % correlation of ellipticity with age, with the younger clusters being flatter on average than the older clusters which were similar to galactic globulars in shape. They suggested this was the result of internal evolution of the clusters. Van den Bergh & Morbey (1984) demonstrated that this correlation was not statistically significant after the dependency of ellipticity on luminosity was removed, given that the brightest blue clusters are more luminous than the brightest red clusters, so making these two correlations not

mutually exclusive. A two-tailed Kolmogorov-Smirnov test showed that the hypothesis that the LMC and galactic globulars are from the same parent population with the same ellipticity distribution can be rejected at the 99.2% confidence level.

The aim of the current paper was to investigate the internal variations of elliptical parameters in a sample of LMC clusters, observations of which were collected at the Mount John University Observatory (MJUO), New Zealand. Due to the small (1m) size of the telescope and the primary aim of the campaign being the derivation of colour magnitude diagrams, the observed clusters tend to be young (Searle et al. (1980) Class III and lower). Initially, a standard package was used to fit ellipses to the clusters, but dissatisfaction with its results led to the use of a moments based technique (as outlined by Stobie 1980a,b and described below).

## 2 METHOD

A major advantage in using moments (see Larson, 1982, for a general background) for image analysis lies in their ease of calculation, e.g. the summation for the second moment can be calculated without knowledge of the mean, which is only needed in the final step:

$$\sum_{i=1}^n (x_i - \bar{x})^2 f_i = \sum_{i=1}^n x_i^2 f_i - \bar{x}^2 \sum_{i=1}^n f_i$$

where  $f_i$  is the intensity of the  $i$ -th background subtracted  $x$  pixel. The  $x$  axis zeroth and normalised first order moments

$$\sum_{i=1}^n f_i \text{ and } \frac{\sum_{i=1}^n x_i f_i}{\sum_{i=1}^n f_i}$$

can be easily interpreted as the object's total intensity and the normalised intensity weighted  $x$  centroid. The sec-

NGC	F & F		G & H		K	G
	Ellip	PA	Ellip	PA	Ellip	Ellip
1651	0.03	-	0.31	126	-	-
1751	0.12	55	0.26	133	0.12:0.9	-
1751	-	-	-	-	0.16:0.5	-
1754	0.06	38	0.11	108	-	-
1783	0.25	64	0.19	72	-	-
1786	0.02	-	0.09	166	0.12	0.00
1806	0.09	9	0.19	159	0.07:1.8	0.05
1806	-	-	-	-	0.12:0.9	-
1835	0.21	88	0.17	77	0.21:0.16	0.21
1835	-	-	-	-	0.14:0.13	-
1835	-	-	-	-	0.19:0.3	-
1846	0.08	151	0.23	129	0.07:1.9	0.13
1846	-	-	-	-	0.16:0.11	-
1917	0.07	168	0.29	4	0.15	0.00
1978	0.33	150	0.30	159	-	-
2019	0.07	139	0.20	124	0.17:1.0	-
2019	-	-	-	-	0.23:0.5	-
2108	0.11	80	0.18	115	-	-
2121	0.18	21	0.32	64	-	-
2154	0.17	36	0.13	42	-	-
2155	0.08	102	0.27	76	-	-
2173	0.06	70	0.27	141	-	-
2210	0.07	78	0.12	82	-	-
2213	0.01	-	0.26	91	-	-

**Table 1.** Literature values for ellipticities and position angles (PAs) of LMC clusters common to Frenk & Fall (1982) and Geisler & Hodge (1980). The latter is given in the column G & H, and the former under F & F. Where available, the ellipticity values of Kontizas et al. (1989) and Geyer et al. (1983) are also shown. These are in columns headed K and G respectively. Note the frequent discrepancies, even for clusters which are given as very elliptical in one catalogue (e.g. NGC 2121, 2155, 2173 etc). Kontizas et al. claim that such differences are due to internal variations in the clusters, and so the radii that an ellipticity is measured at must also be specified. Where Kontizas et al. have given more than one value for a cluster, the values are given on subsequent lines. The radius the ellipticity was measured at is given in arcminutes as the value after the colon. Generally they measured ellipticity at the half mass radius (see King, 1966a), which is a constant throughout a cluster’s dynamical evolution.

ond order moments are harder to interpret, but give information on the structure of the pixel cluster. For a continuous two dimensional distribution, the second order moments are:

$$\begin{aligned}
 U_{xx} &= \iint \frac{(x_1 - \bar{x}_1)^2 dx_1 dy_1}{A}, \\
 U_{yy} &= \iint \frac{(y_1 - \bar{y}_1)^2 dx_1 dy_1}{A}, \text{ and} \\
 U_{xy} &= \iint \frac{(y_1 - \bar{y}_1)(x_1 - \bar{x}_1) dx_1 dy_1}{A}
 \end{aligned}$$

where area  $A$  of the ellipse is  $\pi ab$ .  $a$  and  $b$  are defined conventionally as the ellipse semi-axes. We assume that the ellipse is centred on the origin, i.e.  $\bar{x}_1 = \bar{y}_1 = 0$ . Following Stobie (1980a,b) the size, orientation ( $\theta$ ), and ellipticity ( $e = 1 - \frac{b}{a}$ ) can be calculated of an ellipse fitted to a distribution above the detection level:

$$\theta = \frac{1}{2} \arctan \left( \frac{2U_{xy}}{U_{xx} - U_{yy}} \right) \quad (1)$$

$$a = \sqrt{2 \left( (U_{xx} + U_{yy}) + \sqrt{((U_{xx} - U_{yy})^2 + 4U_{xy}^2)} \right)} \quad (2)$$

$$b = \sqrt{2 \left( (U_{xx} + U_{yy}) - \sqrt{((U_{xx} - U_{yy})^2 + 4U_{xy}^2)} \right)} \quad (3)$$

Similar equations can be derived for weighted moments. Weighted first order moments were used to determine the centre of the pixel distribution (Dodd & MacGillivray, 1986), while the ellipse fitting applied no weighting. The latter results in the distribution’s determined shape and orientation being more representative of the overall distribution, rather than being skewed by the brighter central regions. In asymmetric distributions, the former point means that the derived centre is the centre of mass.

## 2.1 The fitting software

A Fortran program was written based on equations 1, 2, and 3, using the IRAF<sup>\*</sup> Imfort libraries for the image manipulation routines (details on IRAF at VUW may be found in Banks, 1993). Threshold values were read from a file. The image’s background was estimated using the IRAF *imex* tool in clear (star and cosmic strike free) regions of the image.

The image pixel array was scanned starting at (1,1). The array dimensions were automatically determined by the software. The first direction of search was along the x axis. When the end of this row was reached, the x position was reset to 1 and the y position incremented. This continued until the opposite corner of the image was met. When the intensity of the search’s current pixel was above the threshold set for the ellipse fitting, an interior defined seed fill algorithm (see p86, Rogers, 1988) was commenced, and the x and y positions of the pixel were pushed onto a stack. If the stack contained other pixel values, the following occurred: The pixel positions were popped from the stack, and the corresponding (x,y) position flagged in a boolean array of identical dimensions to the image. Eight way connectivity (see p84, Rogers, 1988) was assumed, so all pixels around the current one were examined in turn. If the new pixel had an intensity above the threshold and had not been marked as detected, its position was pushed on to the stack. The end result was that all pixels with intensities above the threshold and contiguous were detected as an individual pixel distribution. This subarray was then passed to the moments analysis subroutine, to evaluate  $a$ ,  $b$ , and  $\theta$ . The size, centre, orientation, and ellipticity of the distribution were then written to disk. Once all pixel distributions had been detected and measured, the next value in a file containing the intensity threshold values was read. The detection array was cleared, and the search commenced again from position (1,1). In practice, the threshold step direction was towards the background, corresponding to an increase in the dimensions of the pixel distribution, allowing examination of the variability of the ellipse parameters describing the star cluster with radius from the cluster’s centre. Further software

<sup>\*</sup> Image Reduction and Analysis Facility: courtesy of the National Optical Astronomical Observatories, which are operated by the Association of Universities for Research in Astronomy under co-operative agreement with the National Science foundation.

Ellipticity $e$			Angle $\theta$	
In	Out	Ratio	In	Out
0.033	0.034	103.0	90.0	89.5
0.200	0.199	99.7	0.0	0.0
0.250	0.250	100.0	0.0	0.0
0.500	0.495	98.9	115.0	114.5
0.571	0.569	99.3	110.0	109.9
0.631	0.626	99.2	45.0	45.0
0.792	0.784	98.9	145.0	145.0
0.800	0.794	99.3	175.0	175.1

**Table 2.** Ellipticity and Orientation Angle values: Input and output ellipticities ( $e$ ) and orientation angles ( $\theta$ ) are shown for a few selected tests, showing that the input values are well recovered by the moment analysis technique. Ratio gives the output ellipticity as a percentage of the input value. The angles are given in degrees.

allowed the preparation of isophotal maps of the ellipses, as well as graphs of the detected pixels for a given threshold.

This program was carefully tested. Initially uniformly weighted ellipses were generated and placed into an array with an arbitrary background level. These were then submitted as noiseless images to the program. 757 trials with different input  $a$ ,  $b$ , and  $\theta$  values showed that the  $a$  and  $b$  were generally slightly overestimated by  $\sim 0.08 \pm 0.06$  pixels (see Table 2 for some representative tests). The variations with angle are due to the discrete nature of the fitted ellipse as pixels. As the ellipticity of the cluster became less in tests, it was found that although the scatter was constant, the difference for  $a$  decreased while that for  $b$  increased, as might be expected. The ellipse generating function of the testing program used the parametric equations for an ellipse to define the boundary, and then block-filled the interior. Real numbers for the boundary's  $x$  and  $y$  positions were converted into integers, indicating a boundary pixel. In comparison with the superior approach of recognizing that pixel  $(x, y)$  extends  $\pm 0.5$  in both dimensions, the  $x$  and  $y$  centroids are displaced by  $-0.5$  from the input values.

The typical FWHM of the programme images was 5 pixels and the ellipse fitted to the star clusters ranged out to 100 pixels. The trials showed that  $\theta$  was recovered by the program to within  $0.10 \pm 0.27$  degrees and the ellipticity to  $0.006 \pm 0.003$ .

### 3 OBSERVATIONS

The observations used were collected over the 1991/92 southern hemisphere summer with the 1m McLellan telescope at MJUO (170° 27.9 East, 43° 59′.2 South) in typically  $\sim 3$  arcsec seeing, using a cryogenically cooled Thomson TH7882 CDA charge-coupled device. This chip has 384 by 576 pixels, each 23  $\mu\text{m}$  square, which at the  $f/7.9$  cassegrain focus used by this study corresponds to 0.60 arcsec (Tobin, 1989). Images were collected using the Photometrics PM-3000 computer running FORTH (Moore, 1974) software with extensive local modifications (see Tobin, 1991), and written to half inch 9 track magnetic tape for transportation back to Victoria University of Wellington (VUW) for analysis. Images from these tapes are then converted into

the FITS (Wells, Griesen & Harten, 1981) format from the native Photometrics one, and were read into IRAF for subsequent reduction. Details on the data pathway and image processing facility established at VUW can be found in Banks (1993). Further details on the Mount John data acquisition system and its characteristics may be found in Tobin (1992).

We initially used the STSDAS<sup>†</sup> *ellipse* function, based on Jedrzejewski (1987), to fit elliptical contours to the clusters. Attempts were made to use DAOphot (Stetson, 1987) to subtract the resolvable stars which would skew the ellipses, and to boxcar smooth these V band residuals over an area comparable to the FWHM. Even when these steps were taken *ellipse* often failed to find solutions over a wide range of radii. However, successful solutions were found for some clusters, such as NGC 1818, which is discussed as an example. When the brighter stars (above a peak intensity of 300 counts) were subtracted from NGC 1818 an angle  $\theta$  around 32 degrees was derived. The ellipticity increased from 0.070 (at a radius of 24 pixels) to a maximum of 0.280 at 33 pixels, before dropping to  $\sim 0.15$  at a 40 pixel radius. Frenk and Fall (1982) give an ellipticity of 0.24 and a position angle of 115 degrees (or a  $\theta$  of 25 degrees in our notation, as  $\theta$  is the rotation anticlockwise from a standard Cartesian  $x$  axis), in reasonable agreement with our results. They do not give a radius for this ellipse, but the ellipses were fitted by eye in the range between the burnt-out centres and the peripheries defined by the background. It should be noted that when *ellipse* was run on the “raw” image of NGC 1818 a uniform ellipticity of  $\sim 0.2$  was found over the radius 10 to 40 pixels.

Similar problems to the NGC 1818 fits were found with NGC 1850, whose raw image resulted in a noisy but effectively constant ellipticity but whose star subtracted image had a linearly increasing ellipticity with radius, and NGC 1856 which exhibited the opposite behaviour in both cases. Zepka & Dottori (1987) fitted ellipses to isophotal contours, and had also noted radial variations in ellipticity and/or axis orientation in all but 4 of their 17 LMC clusters, with a preference for ellipticity to decrease with radius. Fischer et al. (1993) used the *ellipse* program to fit CCD observations of NGC 1850. Although not numerically giving the results, they commented that the ellipses did not fit the distribution well, that the elliptical parameters varied rapidly with radius, and that there was poor agreement between the B and V band fits despite no radial colour gradient being evident in the cluster. The latter contradicts Geyer et al. (1983).

Concerned at this lack of reliability and unsure if any derived trends were real, we adopted the moments technique outlined above, which appeared to be more robust. As a trial, the first image to be fitted was of M81 obtained by Michael Richmond (Princeton), who kindly made the image available. Ellipse fitting to the smooth distribution of this Sb galaxy showed constant values of around 0.3 and 150° for the ellipticity and the position angle. If the disk of the galaxy is assumed to be circular, then M81 is tilted to the line of sight by some 46 degrees. The ellipticity is somewhat less than the 0.5 given in Allen (p288, 1973), as our measure is for the inner nuclear region of the galaxy, not including the spiral arms. The position and inclination angles are in

<sup>†</sup> Space Telescope Science Data Analysis System, courtesy of the Space Telescope Science Institute.

Cluster	Theta	Ellip	Radius
NGC 1818:	0	+	15-137''
NGC 1835:	0	+	17-90''
NGC 1836:	–	–	3-130''
NGC 1839:	0	+	17-145''
NGC 1847:	–	–	5-72''
NGC 1850:	0	+	3-117''
NGC 1856:	+	0	30-107''
NGC 2004:	0	+	7-133''
NGC 2031:	0	–	20-120''
NGC 2133:	–	0	15-125''
NGC 2164:	–	0	15-105''
NGC 2214:	0	0	15-150''

**Table 3.** Variation of Elliptical Parameters for selected LMC Cluster V images. A + indicates that the parameter increased with radius, a – the opposite, and 0 stands for constant with radius. The typical range of the trends were of several tens of degrees in angle and 0.4 in ellipticity. Only general trends are discussed, as in Zepka & Dottori (1987). Noting that the table captions are reversed in Zepka & Dottori (1987), our results agree with them for the clusters NGC 1835, 2004, and 2214, but not for NGC 2031 (which they found to vary in both parameters). Trends evident in NGC 1835 were smooth. The column ‘Radius’ gives the range of radii that ellipses were fitted over.

good agreement with the  $150^\circ$  and  $\sim 35^\circ$  values of Boggis (p288, Jones, 1968).

Having demonstrated the stability of the fitting program on a smooth distribution, we then proceeded to our own LMC cluster observations, with their more irregular morphology partly due to the presence of bright young stars. Table 3 gives the general results of the fitting program on images with the resolvable stars subtracted, while Table 4 presents a comparison for the derived ellipticities with those of Zepka & Dottori (1987) and Kontizas et al. (1989). While overall trends were apparent, large radial variations in  $\theta$  and  $e$  were present even when bright stars were removed and smoothing employed (as before). The results given in Table 4 reveal a somewhat weak agreement between the three studies, which used different techniques on different data sets collected under different seeing conditions. In the case of the current study, the poor seeing experienced would increase the difficulty of detecting and removing bright stars from the clusters. Both the previous studies used PDS scans of photographic plates. Zepka & Dottori (1987) performed least squares fits to isophotal contours, while Kontizas et al. (1989) used a computer-aided interactive procedure where ellipses were fitted by eye to scanned images. No mention is made of seeing by either study. The ellipticities of Kontizas et al. (1989) appear to be biased towards the values at the maximum radius. There are major differences between Kontizas et al. (1987) and Zepka & Dottori (1987) for some clusters, as well as discrepancies with the current study.

#### 4 SIMULATIONS

To test the reliability of the analysis techniques, artificial elliptical star cluster images with known parameters were generated. This was to test if the input parameters could be successfully derived by the two methods. The magnitude

Cluster	Radius (Arcsec)	Ellipticity		
		BDS	K	ZD
NGC 1835	27	0.09		$0.16 \pm 0.09$
...	34	0.11		$0.21 \pm 0.12$
...	46	0.12		$0.26 \pm 0.12$
...	48-90	0.14-0.24	0.14	
NGC 1847	18-30	0.48-0.62	0.29	
...	30-54	0.15-0.62	0.20	
NGC 1850	30	0.20	0.19	
...	48-192	0.18-0.35	0.10	
NGC 1856	24-84	0.01-0.10	0.16	
...	96	0.05	0.05	
NGC 2004	42-60	0.02-0.21	0.20	
...	66-96	0.18-0.28	0.16	
NGC 2031	12-54	0.21-0.44	0.20	
...	17	0.44		$0.46 \pm 0.09$
...	22	0.30		$0.28 \pm 0.13$
...	30	0.27		$0.21 \pm 0.13$
...	51	0.29		$0.21 \pm 0.08$
...	60-114	0.11-0.26	0.11	
NGC 2214	19(a)	0.45		$0.40 \pm 0.14$
...	19(b)	0.45		$0.38 \pm 0.12$
...	26(b)	0.37		$0.39 \pm 0.12$
...	27(a)	0.36		$0.34 \pm 0.13$
...	36(b)	0.34		$0.46 \pm 0.09$
...	43(a)	0.32		$0.30 \pm 0.07$

**Table 4.** Comparison of Ellipticity Estimates for clusters in common with the current study, Kontizas et al. (1987), and Zepka & Dottori (1987). Frenk & Fall (1982) and Geisler & Hodge (1980) did not state what radii ellipticities were measured at. The column ‘Radius’ lists the radii, in arcseconds, that Kontizas et al. (1989) or Zepka & Dottori (1987) estimated ellipticities over. ‘BDS’ gives the ellipticities derived by the current study for the radii, while ‘K’ and ‘ZD’ list the ellipticity given by Kontizas et al. (1989) or Zepka & Dottori (1987). The latter paper presented two different profiles for NGC 2214, which have been indicated as (a) and (b) in ‘Range’. Kontizas et al. (1989) estimated an uncertainty of 0.03 for their ellipticity values.

distribution was calculated using the IRAF *starlist* function, which allowed power, uniform, Salpeter model (a best fit function to the data of McCuskey (1966)), and Bahcall & Soneira (1980) functions to be used. It was decided to use an adjusted spherical King (1962; 1966a,b) model for the placement of stars inside the cluster, on the basis that spherical King models are algebraically simple and have been widely applied to the LMC clusters (e.g. Chun, 1978; Elson, 1991; Fischer et al, 1992, 1993). x and y positions were generated using a pseudo-random number generator (which tests revealed to have no bias). These values were then converted across to polar coordinates centred on the (user set) artificial cluster centre. The tidal, or limiting, radius of the cluster was assumed to vary elliptically. Given the polar coordinates of the random position, a tidal radius was generated for the point. If the point did not fall within this limit, another random position was generated. Once a point fell within its appropriate tidal limit, another random number between 0 and 1 was generated. This was compared with a radial distribution scaled by the tidal radius at the polar angle  $\theta$ , allowing ellipticity to be included. If the random number fell below the distribution’s probability at the point’s radius, a star image was assumed to exist. See Figure 1 for

**Figure 1.** King Profile Distribution: Star positions for a King distribution 0.5 ellipticity artificial cluster are shown.

a King test distribution. Finally, the elliptical distribution could be rotated about its centre. This allowed two 5000 star image  $e = 0.5$  King distributions to be placed at right angles to each other. Reduction of the resulting image by the automatic ellipse fitting software was expected to produce results of zero ellipticity. A slightly greater ellipticity of 0.03 was achieved. A higher ellipticity in the centre of this test image was due to the greater effect of the positions of large individual bright stars in the small fitting region, where they are also more probable due to the increased stellar density towards the centre of a cluster. Above a radius of 3 full width half maxima reliable results were being obtained.

As a further test, ‘flat’ (uniform probability within the ellipse boundary) distributions were sliced up in  $\theta$  (e.g. halves, eighths, etc.), with each slice being cut into equal area segments, so as to check that the radial distribution was being scaled correctly with  $\theta$  (see Figure 2). The solid lines in this figure plot the stellar density when the cluster had been split into two halves containing 40 equal area segments each. The segments were considered to be sectors of a circle. Given that the inner segment radius was 31.5 pixels, a density of 124.4 stars was expected for those segments inside a 100 pixel radius (the  $b$  axis). Examination of the 18 segments within a 95 pixel radius gave a mean of  $122.5 \pm 10.1$  stars per segment, and a median of 123.3. The mean density over the 80 segments was  $62.5 \pm 41.9$ , as expected. When the distribution was sliced into sixths (the dotted lines), the density fell by the expected third. Also note the dropoff of the two sectors centred on the  $y$  axis is more rapid due to the smaller radial size of the sectors, and that they have fallen off completely just above the  $b$  axis length as could be expected for circular regions there.

Given the success of the flat distribution in this, and that the King function used did approach the empirical inner and outer radii functions of King (1966a), we are confident that the Monte-Carlo placement of the stars was performed correctly. Since the co-ordinates and magnitudes of the stars were available, the IRAF *mkob* task was used to create artificial frames. A Gaussian profile was used for the

**Figure 2.** Star counts in a sliced flat distribution: 5000 stars were randomly distributed in a flat elliptical distribution with  $a = 200$  and  $e = 0.5$ .

Point Spread Function (PSF) of the 20,000 stars per artificial frame, together with a read noise value of 7.35 electrons and a gain of 4.27 electrons per decimal unit (being the values for the TH7882 chip used to collect the real observations). 2.4” seeing was assumed in the tests, corresponding to the best seeing conditions experienced at MJUO by this project. An aim was to have a smooth distribution of faint stars, with a few bright ones scattered around in it.

The first test image was of a 0.5 ellipticity cluster, with scaled King radii based on Chun’s (1978) values for the old LMC cluster NGC 1835. These values were 500 and 15 pixels for the tidal and core radii respectively. These latter values were chosen for realism, and used in all the simulations presented below. Trials varying the magnitude zero point had no effect on the derived trends and results. The lowest threshold value used was barely above the background value, being at three standard deviations of the noise above the background. The derived position angle agreed well with the input value, falling within 5 degrees of it. Ellipticity increased linearly from an inner value of 0.3, reaching the input value at the outer radii, and then dramatically dropping at the last “isophotes”. Such a low ellipticity halo containing an elliptical cluster was noted for NGC 2214 by Bhatia & MacGillivray (1988), although the cause in our simulation was simply that the cluster distribution extended off the right boundary of the image (due to slightly asymmetric centring of the cluster in it). This also resulted in the outer ellipses being skewed to the left (but not vertically as symmetry was maintained in that direction).

Concerned that the trends apparent in the image might be due to the placement of bright stars, whose brightness would skew ellipse fits, another image was created with the brightest three magnitudes excluded. 441 stars were ‘lost’ by this process. Fitting showed that throughout the cluster the ellipticity of this smooth distribution was within 0.03 of the input ellipticity, until the boundary problem mentioned above was met. The position angle was stable, although systematically overestimated by one degree, while the  $x$  and  $y$

cluster centres were stable about the input values. Similar trends were found for simulations with all 20,000 stars set to the faint magnitude of -1, although they were slightly closer to the input values (as might be expected since the combined luminosity distribution gradients were more uniform across the image). Such results are in line with what could be expected for smooth distributions, such as in old LMC clusters where the bright stars have long since evolved. Further trials using the original magnitude distribution (i.e. with the bright stars), but with different star placements and ellipticities, showed the following:

- (i) The major axis angle could vary by  $\sim 80^\circ$  with radius, becoming more variable as  $e$  approached zero. However, large variations of  $\theta$  over small radial distances were found in a very ( $e = 0.5$ ) elliptical distribution, due to the random placement of bright unresolved stars.
- (ii) No particular trend in ellipticity with radius appeared to be preferred. Examples were found where ellipticity increased, remained constant, or decreased with radius.
- (iii) Generally the input ellipticity was reached in the outer regions by the ellipse fitting. However, without prior knowledge of this value, it would be difficult to determine that the ‘real’ value of the cluster had been determined. Often, in the simulations it was only met for one or two points.

However, such tests removing bright stars, are not very realistic as the bright stars are correctly ‘removed’ from the cluster image. In practise, it is common (see e.g. Fischer *et al*, 1992, 1993; Elson, 1991) to use a PSF to subtract out the bright stars from an image. This is because it has been widely recognized that such stars will bias ellipse (and profile model) fits by their placement and intensity. We therefore used the IRAF tasks *daofind* and *substar*, which are based on DAOphot (Stetson, 1987). Outer radius bright stars in uncrowded areas were used in an iterative process to construct the empirical corrections to a Gaussian PSF. This process concluded when tests showed that stars in uncrowded regions were being cleanly subtracted from the image. All the stars in the image that could be identified by DAOphot were, and the bright ones (above a user set intensity limit) subtracted off using the modeled PSF. The moment analysis software was then run on the image. Ellipticity was found to increase with radius, reaching the input value at  $\sim 4$  times the PSF’s FWHM, and then dropping away (before the outer isophotes were met). The range of the trend was 0.15 in  $e$ , which is comparable with the trends found in our observations and Zepka & Dottori (1987). The position angle was always within 3 degrees of the input value, excluding severe disturbance in the cluster centre. Similar results can be seen in the results of Zepka & Dottori (1987), contributing to their gradients. These trends are presumably due to the unresolved bright stars in the cluster centre. It is interesting to note that moment fitting of the original image showed the ellipticity was recovered more rapidly with radius than the star subtracted image, and that this ellipticity was more constant until the boundary problem was met. It is likely that poor background estimates in crowded regions leads to either positive (under-subtraction) or negative (over-subtraction) residuals, resulting in spurious radial gradients.

*Ellipse* was also run on some of the test images, to see how well it agreed with the moments technique in light of

our concerns mentioned above. Even in clusters of 0.4 and 0.5 ellipticity trends were evident in  $e$ , accompanied by  $\theta$  ranging up to 70 degrees. Low ellipticities were found for cluster centres. The input ellipticity was not recovered over substantial radial intervals by the software, and was not obvious in plots of  $e$  against radius (i.e substantial plateaus corresponding to the input ellipticity’s value were not seen). Problems were often encountered with *ellipse* failing to iterate towards a solution. It does not appear that *ellipse* is suitable for young clusters, with their clumpy distributions, even when measures are taken to exclude the brightest pixels from given ellipse fits.

## 5 CONCLUSIONS

Radial variations in the ellipticity and position angle of LMC clusters have previously been taken to indicate that they are triaxial structures in equilibrium (Zepka and Dottori, 1987). We believe, in light of our simulations, that caution should be exercised in the interpretation of ellipse fitting of young populous clusters. Stochastic effects in the placement of bright stars, which can not all be both detected and cleanly subtracted from an image using standard (and previously used) techniques, will result in spurious trends. Such problems will not be evident in large bodies observed at low resolution (such as M81) or evolved old clusters (such as NGC 1835), both with smooth radial distributions. The fact that trends were observed in NGC 1835 suggests that its radial variations may be real.

## 6 ACKNOWLEDGEMENTS

The authors are grateful for generous time allocations at the Mount John University Observatory, and to the New Zealand Foundation for Research, Science and Technology for partial funding of this project, in conjunction with the VUW Internal Research Grant Committee. TB acknowledges partial support during this study by the inaugural R.H.T Bates Postgraduate Scholarship of the Royal Society of New Zealand. We would like to thank Acorn New Zealand for the loan of an R260 machine, on which some of this paper’s work was performed, and also acknowledge the help of the Referee, Dr. R.S. Stobie.

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